“Can We Survive Climate Change? The Critical Role of Adaptation”

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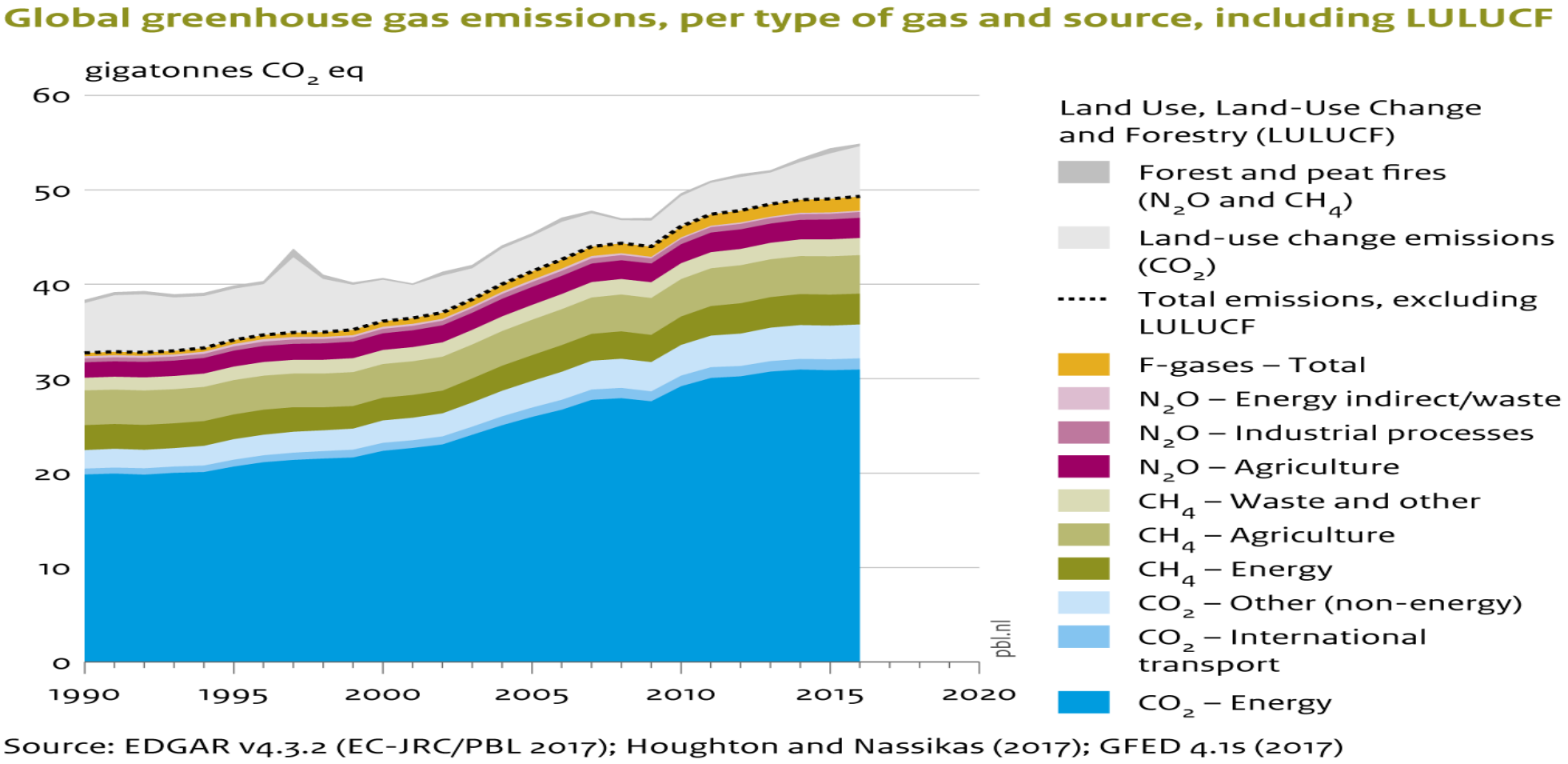
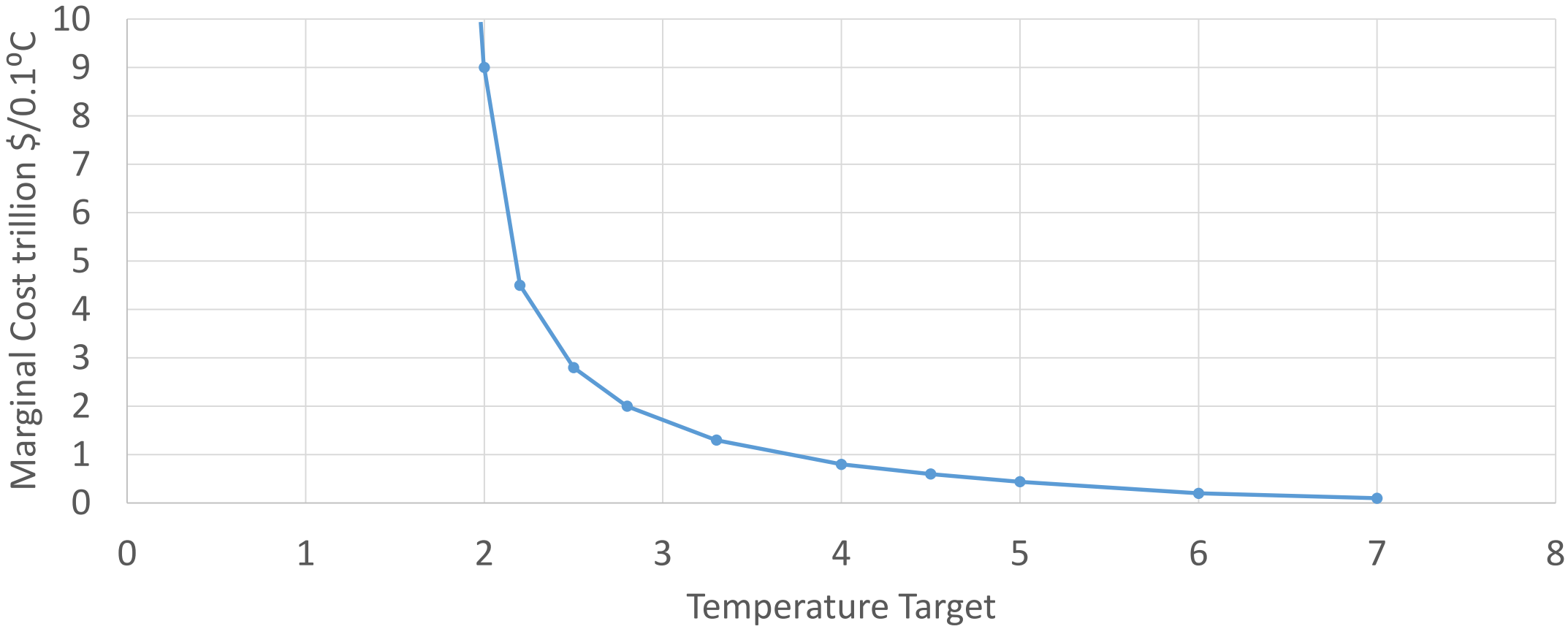
Global greenhouse gas emissions are still growing



Why is mitigation failing?

- Weak Global Governance
  - Efficient mitigation requires global cooperation
    - Countries must agree to a single price for greenhouse gases
    - With fewer participants, mitigation is much less effective
  - Not in any country's self-interest to mitigate all by itself
    - Costs will be paid entirely by self and benefits will be shared broadly
- Mitigation is expensive
  - Lower temperature targets cost a lot more
  - Must mitigate a lot sooner, leave more capital stranded
  - People do not support all mitigation activities
    - Nuclear power, more expensive energy, more hydropower, land use controls

Marginal Cost ($trillion/0.1ºC)



How much mitigation can we expect?

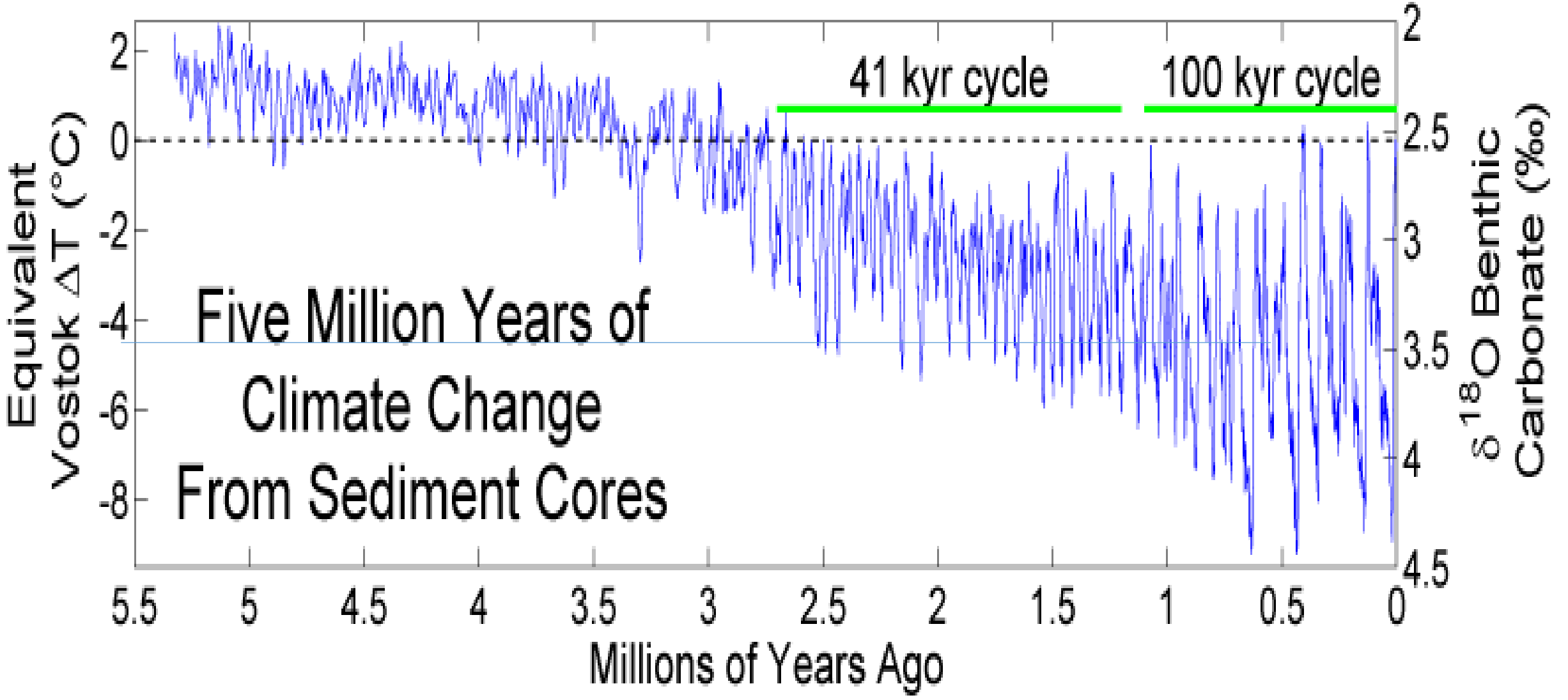
- Paris Agreement sought target of 1.5^{o}C but made mitigation commitments that would lead to 4^{o}C warming
  - Not clear countries will meet their own targets
- Limiting long run temperature to 4-5^{o}C is possible
  - Not that expensive
- But can we survive that much warming?

What are the biggest threats from warming the planet 4-5^{o}C by 2150-2200?

- Ecosystem collapse
- Sea level rise of 64 m
- Food supply collapse
- Health effects (heat waves, infectious disease, ozone)

Ecosystem Collapse

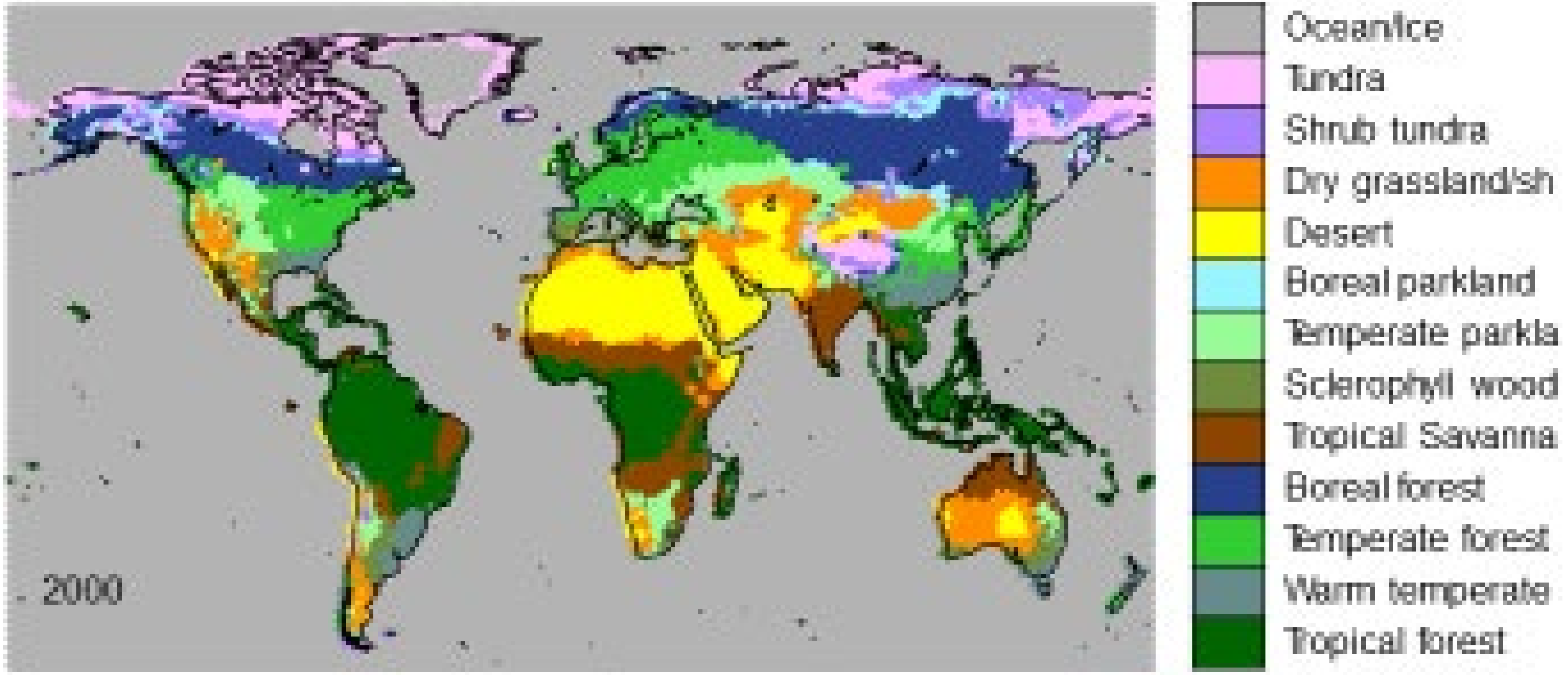
- Are ecosystems robust to global temperature?
- Ecosystems have survived past warmer climates of at least 2^{o}C
- Ecosystems have survived wide swings (9^{o}C) in global temperature over last million years
- But can ecosystems survive 4-5^{o}C?

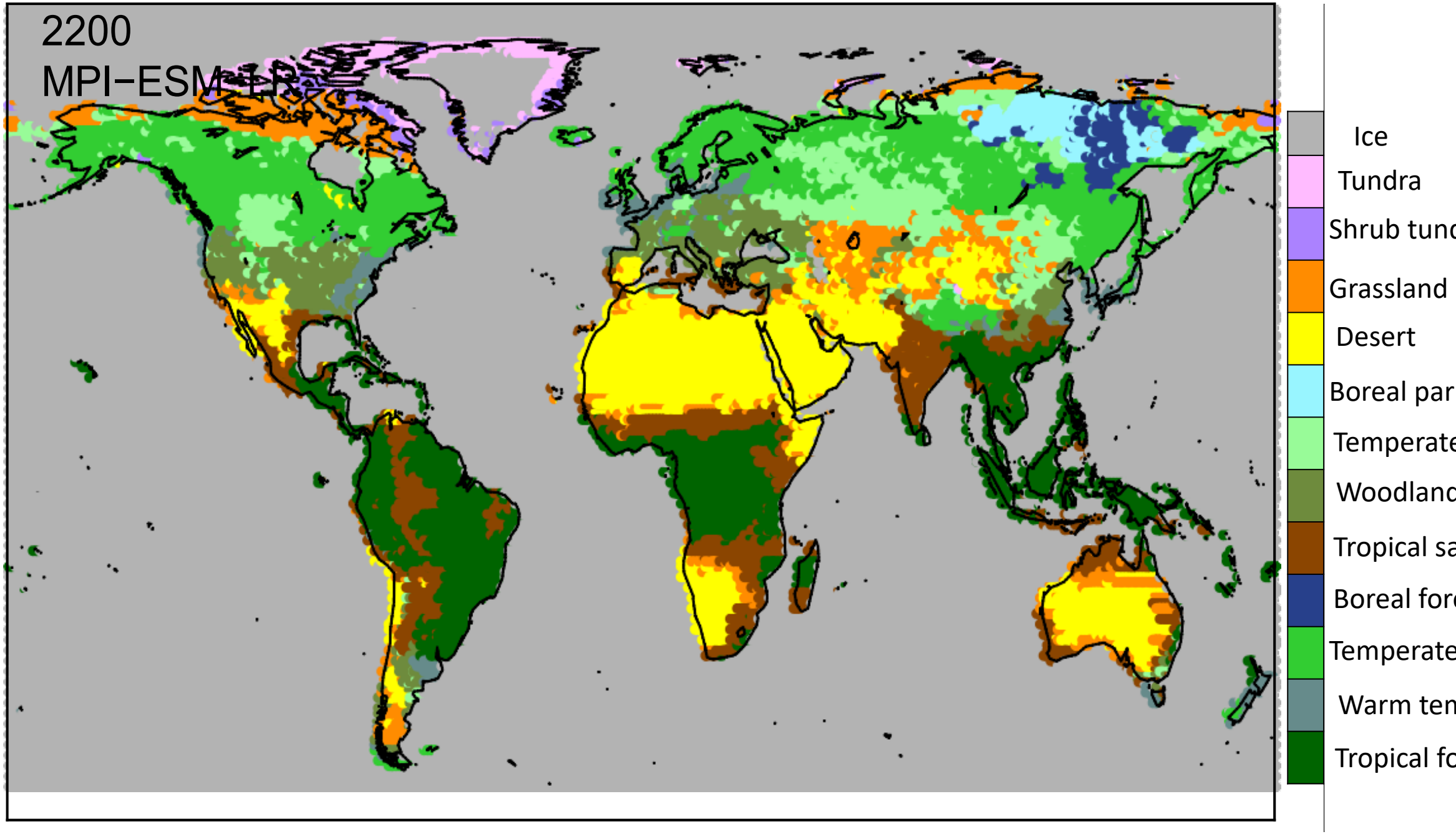

Five Million Years of
Climate Change
From Sediment Cores
41 kyr cycle
100 kyr cycle
Equivalent
Vostok ΔT (°C)
2
0
-2
-4
-6
-8
δ18O Benthic
Carbonate (‰)
2
2.5
3
3.5
4
4.5
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Millions of Years Ago

Ecosystems move across the earth with warming

- Models and past records show ecosystems adapt to warmer temperatures by moving poleward and to higher altitudes
- Shares of land change across systems
  - Parkland and temperate forests replace tundra and boreal forest in high latitudes
  - Tropical forest, warm temperate forest and woodlands replace temperate forest in mid latitudes
  - Savannah starts to replace tropical forest and deserts start to replace grassland and parkland in low latitudes
- Overall land changes are offsetting up to 2150 and then become harmful

Current Ecosystems of World




2200
MPI-ESM-LR
Ice
Tundra
Shrub tund
Grassland
Desert
Boreal par
Temperate
Woodland
Tropical sa
Boreal for
Temperate
Warm tem
Tropical fo

Other ecosystem changes from warming

- Models predict forest, woodland, and parkland NPP (growth) increases up to 6^{o}C (2150) and then flatten
- Models are split concerning whether biomass increases or falls
- Past climate changes from glacial cycles have not led to dramatic loss of species
- Sudden changes in climate from meteor strikes and large scale volcanic explosions have led to mass extinctions

Humans can facilitate ecosystem adaptation

- Forest companies can shift species and varieties to help commercial managed forests move poleward
- Conservation can take a dynamic approach to saving ecosystems by facilitating change
  - Design conservation pathways that give ecosystems space to move
  - For example, setting aside corridors along north-south mountain chains such as the Appalachians, Rocky Mountains, and Sierras
  - Conservation can facilitate change- assist invasive species
  - Actively manage conserved lands
- We can help endangered species adapt to new locations

Sea level rise (SLR)

- Warming above 2C increases probability that ice sheets will melt
- Past records of glacial cycles reveal dramatic swings in ice sheets and ocean levels over long periods of time
- Existing ice sheets hold a lot of water
  - Greenland-6 m of potential sea level
  - Antarctica-58 m of potential sea level
- Over 136 port cities with over a million people would be inundated by 64 m of SLR

How will SLR change over time?

- A sudden change in mean sea level of 64 m would have catastrophic effects on humans
  - All but a few major cities would be inundated
  - Ports (trading) would be lost
- But global warming does not provide enough heat to melt all of the ice sheets suddenly
- Ice sheets will take 500 to 10,000 years to melt completely
- Consequence is likely doubling of sea level rise (SLR)
  - Over next century, that implies SLR going from 3 mm/yr to 6 mm/yr

Can we adapt to a doubling of SLR?

- Next century
  - Build walls around ports and urban areas
  - Start with low walls and gradually over decades increase height
  - Retreat from less developed areas as they become inundated
- Far future
  - Consider large scale protection projects
    - Dam the Mediterranean at Gibraltar
    - Dam San Francisco Bay at Golden Gate Bridge
    - Dam New York harbor
    - Dam Baltic Sea in Denmark
  - Retreat inland

SLR damage

- If there is no adaptation, a doubling of SLR would cause a global net present value damage of about $11 trillion (Diaz 2016)
- With urban protection and rural retreat, however, the overall cost of doubling SLR is just $1.7 trillion
- SLR remains an important damage of future warming but adaptation reduces the damage by 7 fold

Is the global food supply robust?

- Crops and livestock all prefer specific temperature ranges
  - Yields fall as temperatures move out of these ranges
  - Yields could fall 6-8%/^{o}C
  - Crop yields increase with CO_2 (carbon fertilization)
    - Offsets some of the warming effect
  - Expected increase in precipitation would also help offset losses
  - Nonetheless, warming without any adaptation is likely to gradually reduce global food output

Farm adaptation

- Farmers could mimic nature and move crops poleward
  - Farmers can switch crops and livestock as temperatures warm effectively moving crops and livestock poleward
  - Movement effectively keeps crops in desired temperature range- no yield loss
  - Eventually, though, limited land available poleward
- Intensification
  - Historic rate of productivity increase is 2%/year
  - Primarily earned by adding more inputs
  - Improvements in varieties have also helped
    - Countries can subsidize research into new varieties

Farmers can irrigate

- Farmers can irrigate crops
  - Increases yields and increases temperature tolerance of crops
  - Southeast Asia has average temperatures of $30^{o}C$ and most productive farms in the world because of irrigation
  - In many places, limited water available
  - Shift farming to places with abundant water
- Water management
  - Water can be managed more efficiently so leads to higher value
  - This will mean less water for agriculture
  - But yields/water can be substantially improved with investments into technology
    - Move from gravity irrigation to drip irrigation

Farm Adaptation

- A 5^{o}C warming by 2150 would reduce aggregate global food supply by 30-50%
- With carbon fertilization, global food supply would likely fall by 10-40%
- With crop movement, irrigation, and intensification, yields could continue to increase at 2%/yr, causing overall global food supply to increase by 130 fold
- Global warming loss can be compensated through intensification and adaptation- very likely making global food supply robust

Heat waves

- Heat waves cause significant deaths
- Can prevent deaths with cooling
  - Fans in developing countries
  - Air conditioning in middle and high income countries
  - As countries develop, more people are middle and high income
    - Air conditioning will spread throughout low latitudes
    - Heat wave deaths will likely fall
    - Effect of heat waves will be largely cost of air conditioning
      - Increased demand for energy not more deaths

Infectious disease

- Warming will allow many powerful infectious disease to spread
  - Diarrhea, respiratory disease, malaria, dengue fever, and others kill millions today
  - Climate change could permit these diseases to spread
  - Without any response, climate change could expose millions of additional people
- Public health measures can almost eliminate these diseases
  - Middle to high income countries control most of these diseases
  - World Bank predicts future economic growth will largely eliminate these diseases as countries transition away from being very poor
- Global public health response can address remaining problem areas
  - Remaining adaptation cost in public health expenditure but not deaths

Ozone

- Warming will lengthen warm weather in which ozone will form
- If no measures are taken, will lead to higher ozone exposure
- Ozone harmful to plants (trees and crops) and people
- Adaptation is to control precursors (Nitrogen oxides and VOC’s)
  - Can limit ozone with air pollution control devices

Conclusion

- Poor mitigation response is likely to lead to a warmer planet
- Society can adapt to each threat of a warmer planet
- There will be remaining damage and adaptation will require resources
- But we will survive a warmer planet
- If we overestimate our ability to adapt or the remaining damage is much higher than we expect, we can turn to cooling the planet on purpose with geoengineering